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MINIMIZING TOTAL SETUP COST FOR A METAL CASTING COMPANY

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ABSTRACT

The optimizing sequence of production for a set of customer orders – in order to minimize machine set-up time and costs – is one of the typical problems found in many manufacturing systems. In this paper, we develop a simulation model to capture a practical system of a metal casting company in Queensland, Australia, and optimize the production sequence for a set of customer orders. The method addressed in the paper can be applied to other optimization problems in manufacturing industry.

1 INTRODUCTION

In a business and manufacturing environment, most companies face the pressure of rearranging and optimizing their production schedules and flow-lines in order to meet their customer orders. These concerns are considered simultaneously with the need to save cost and use material efficiently. The main objective is to satisfy customer demands with incurred costs as low as possible. In the past decades, such issue has received extensive attention. Computer simulation is widely used to represent manufacturing systems for the purpose of aiding decision support systems and strategies at the operational shop floor levels, e.g., Seliger et al (1986), and Garside (1988). Udo and Gupta (1994) use the simulation results to predict future output values based on various given input conditions. As a consequence, the cost, time and risks are reduced compared to experimenting with decision alternatives in real time systems. Shires (1988) integrates discrete event simulation into a decision support system at the operational planning and control levels of batch manufacturing, and presents how on-line short-term planning decisions are made. Rogers et al (1988) use knowledge-based to simulate and control automated manufacturing cells, and develop the knowledge-based system which can be applied to the control and scheduling of modular flexible machining cells.

This paper develops a simulation model for a metal production company based in Queensland, Australia. The cost concerns of the metal casting company focus on the extra time and energy spent in changing the set-up configurations in the manufacturing system. The need for changing the machine set-up is due to the various customer orders that vary in material type, make and dimension. The objective is to minimize the cumulative total cost incurred in changing of machine set-up. The simulation model is built to assess the set-up cost of every possible combination of the orders. The paper is organized as follows. The next section briefly describes the company's manufacturing system, and introduces the problem on which the paper focuses. Section 3 builds a simulation model to assess the customer orders and performs a grid search for finding the best sequence of orders, which also results in the least total set-up cost. Finally, section 4 concludes the paper.

2 PROBLEM DESCRIPTION

A pilot plant focuses on the production of small-sized aluminum alloy billets as feedstock to downstream processing industries. The billets production is in the range of 10 to 150 mm sizes and the material of the billet is aluminum mixed with various types of alloys. Within the casting process, there are three types of casting structures available, the conventional, thixomold and metal-matrix. The thixomold castings are developed to fill a marketing niche where the demand for weight reduction in material is sought. This type of light metal provides a sustainable and environmentally friendly solution to improving energy efficiency in the aerospace, electronics and automotive industry. The plant layout of the manufacturing department is shown in Figure 1.

In the system, molten aluminum metal and alloy are first mixed in the furnace. The molten material then flows to the casting operation and is processed into billets of various sizes. The feedstock production system in Figure 1 depicts a system that runs continuously to meet various customer orders. Within the furnace itself, there are about 100 alloy types to be selected from to mix with the aluminum metal. At the casting stage, there are three types of casting structures available for selection: conventional, thixomold, and metal-matrix. The billet sizes may range from 10 mm to 150 mm in diameter size. Statistically, the alloy types from customer orders follow the uniform distribution on the interval [1, 100], and the diameter sizes from customer orders follow the uniform distribution on the interval [10, 150].

Due to different customers wanting different sizes and types of products, extra costs are incurred where there is a huge variability in orders. For our system, there are the following three changes: (a) change of alloys, (b) change of structure types and (c) change of sizes of products.

(a) The change of alloys incurs extra time for changing the material in the machine. This happens after the furnace activity. Apart from the change of set-up, the alloy material has to be removed from the chambers, producing scrap metal which will be sent for remelting. Moreover, energy is spent in moving material around whenever the material is consumed inefficiently in the process. The estimated cost for the change in alloy set-up is $41.68.

(b) The change of machine types occurs at the casting stage. The estimated cost for the change in structure set-up is $18.51.

(c) The change of casting or product sizes also occurs at the casting stage. The estimated cost for the change in diameter set-up is $9.25.

The beginning process of producing the first order usually requires no changes in set-up. However, for the sake of further investigation, it is assumed here that the entire manufacturing process begins with an initial set-up of Alloy Type 1, Conventional Structure and Diameter Size 10. We use a sample of five orders to illustrate the problem here. The set of orders, A, B, C, D and E, are presented in Table 1. These five orders are the actual orders received in

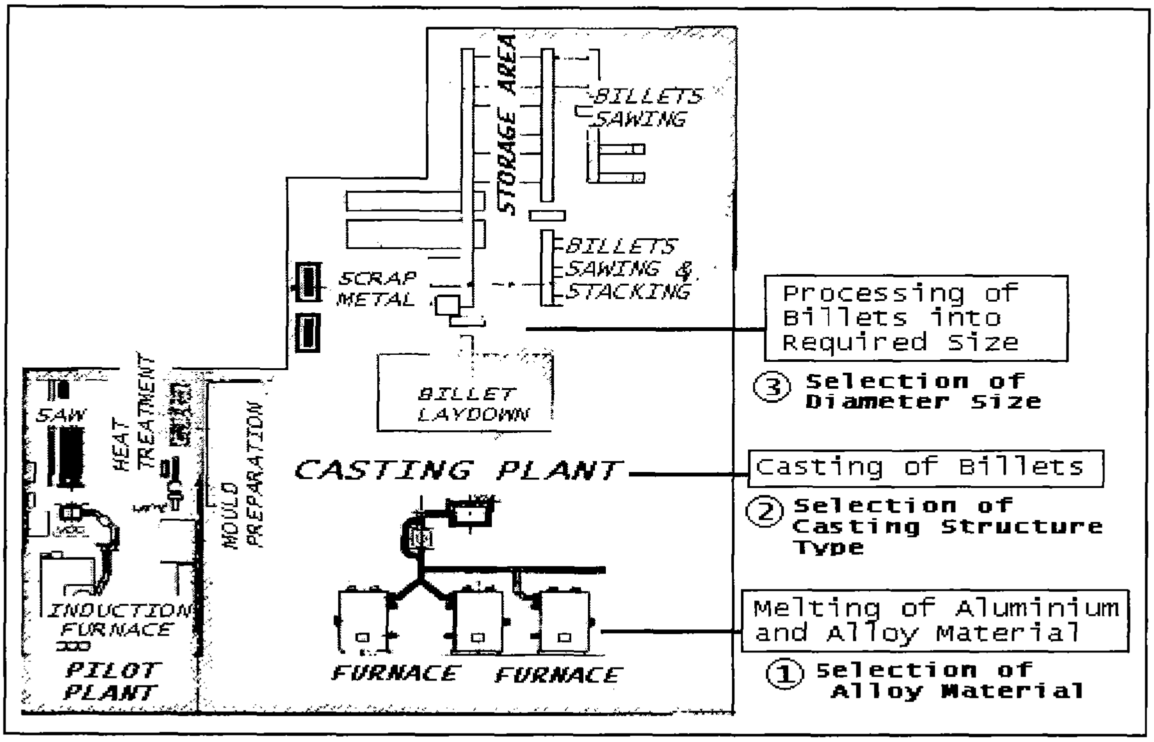

Figure 1: Layout of the Manufacturing Department

a particular day, which is the approximate number of orders that are expected to receive on a daily basis. The costs incurred for set-up changes of material, machine structure and diameter size are defined as costs X, Y and Z, respectively. The set-up costs are incurred after the processing of every order, except for order D where the diameter matches that of order C, which is 15 mm. Figure 2 shows the cumulative total costs incurred whenever the change of set-up is required in the processing of the next order. The total set-up cost incurred at the end of the five orders for the first case is $337.95.

Table 1: First Sequence of Orders

Order	Material Type	Machine Type	Diameter (mm)	Cost X Incurred	Cost Y Incurred	Cost Z Incurred
A	50	*MM*	25	Yes	Yes	Yes
B	33	*Conv*	30	Yes	Yes	Yes
C	50	*Thix*	15	Yes	Yes	Yes
D	10	*MM*	15	Yes	Yes	No
E	25	*Conv*	25	Yes	Yes	Yes

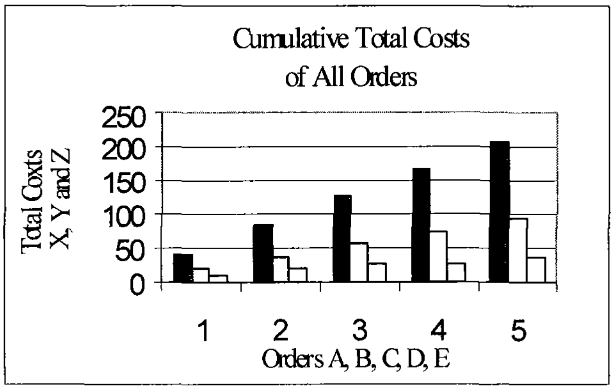

Figure 2: First Cumulative Total Setup Costs

In the next set of sequences shown in Table 2, orders A and B are switched. This re-sequence of orders results in a matching pair of material type, orders A and C, and a matching pair of diameter selection, orders C and D. Since the set-up of the machine structure is initially the conventional type, Conv, no change of set-up is required for the casting machine for the processing of the first order, B. The cumulative costs for the second sequence of orders are shown in Figure 3. The total set-up cost incurred at the end of the five orders for the second case is $277.76.

Without doubt the higher extra set-up costs result in a higher total operational cost. The interesting problem is to find the optimal sequence of order sequence so as to minimize the total machine setup cost. For the above practical

Table 2: Second Sequence of Orders

Order	Material Type	Machine Type	Diameter (mm)	Cost X Incurred	Cost Y Incurred	Cost Z Incurred
B	35	*Conv*	30	Yes	No	Yes
A	50	*MM*	25	Yes	Yes	Yes
C	50	*Thix*	15	No	Yes	Yes
D	10	*MM*	15	Yes	Yes	No
E	25	*Conv*	25	Yes	Yes	Yes

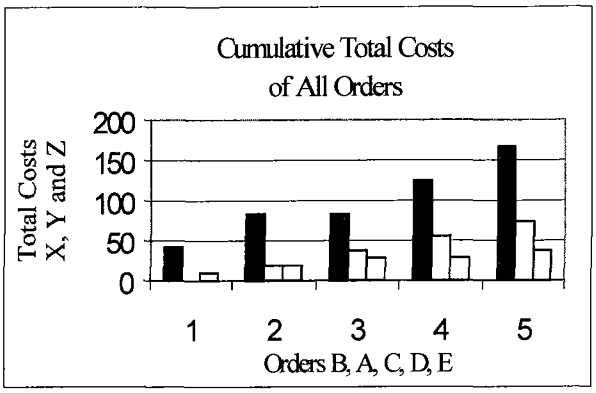

Figure 3: Second Cumulative Total Setup Costs

system, since the number of the orders is small, we can obtain the optimal sequence of the orders through permutation based on simulation. Next section will use simulation to obtain the optimal sequence of the given orders by permutation.

3 SIMULATION BASED SOLUTION

In this section, we develop a simulation model to capture the manufacturing system. Through the simulation model, we calculate the total setup costs for all the possible sequences, and then obtain the optimal sequence with minimal total setup cost. Similar studies of sequencing orders or jobs for minimizing costs in the production stream are conducted by Vickson (1980) and Van Wassenhove and Baker (1980), where all the data used are known and fixed, and all the uncontrollable factors such as machine breakdowns are eliminated.

The simulation model shown in Figure 4 is developed to represent the manufacturing system in Figure 1. Each activity block in the model contains the necessary time and cost that capture the actual situation in the manufacturing system. The three set-up costs, X, Y and Z costs, are executed in the model whenever alloy type, structure type or diameter size of the following orders do not match. The model can generate any range of orders that may be keyed in through option menus shown in Figure 5. The alloy type

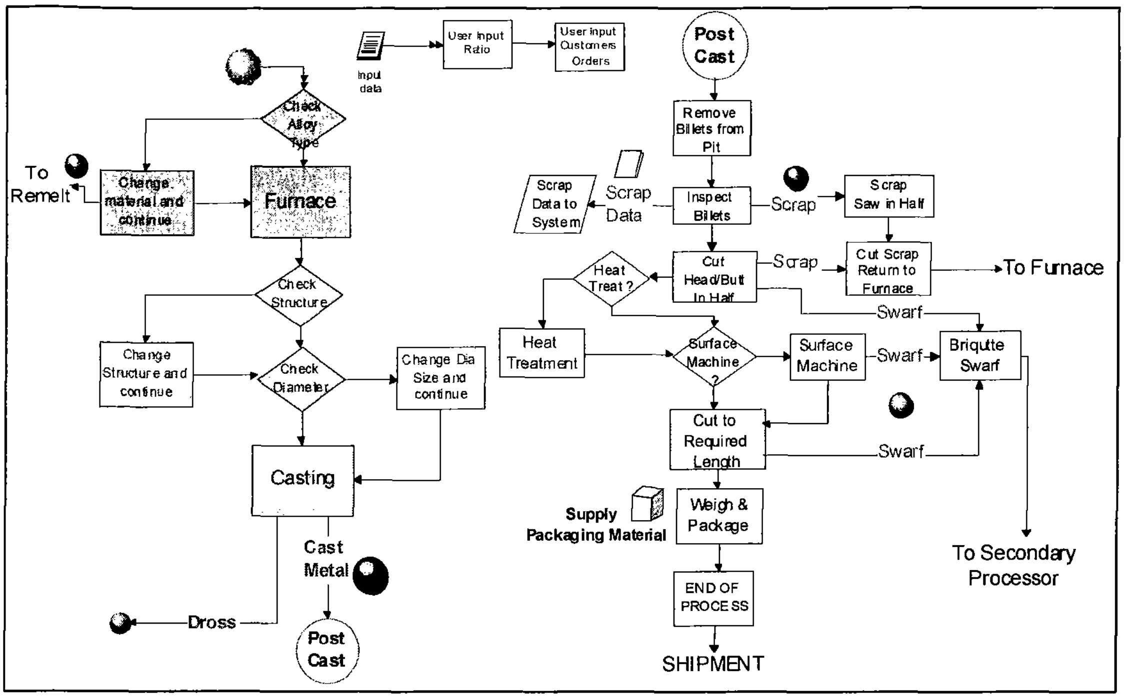

Figure 4: Simulation Model of the Manufacturing System

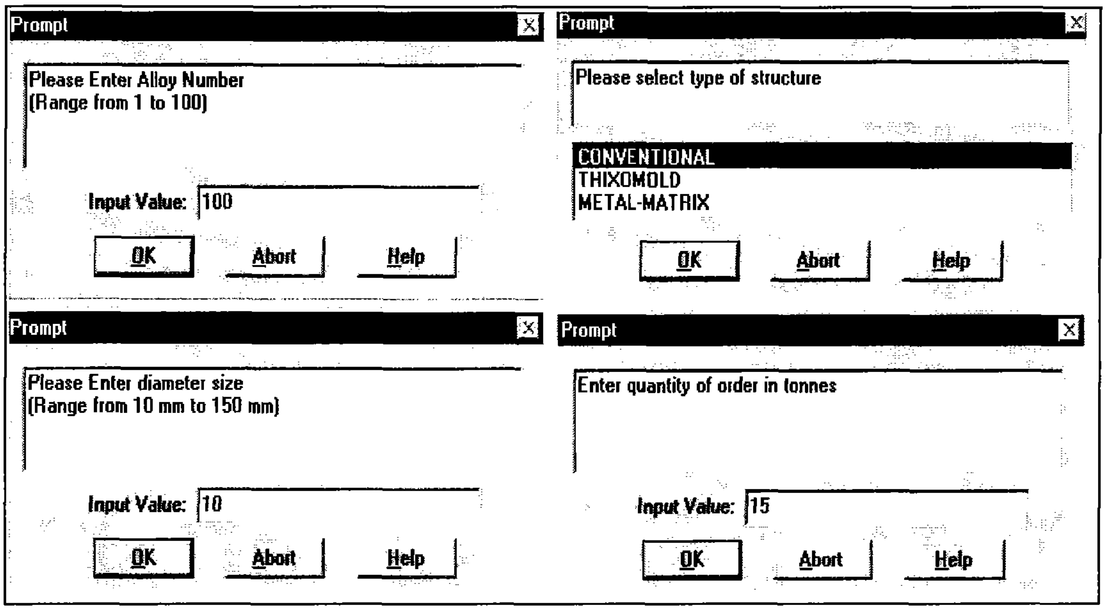

Figure 5: User Selection Menu

of each order is generated according to the uniform distribution on the interval [1, 100], and the diameter size of each order is generated according to the uniform distribution on the interval [10, 150]. During the simulation run, the user may continue to key in as many orders as required, or select the "end of orders" option shown in Figure 6.

Here we use the sample case presented in Section 2 as an illustration of our simulation results. For the five orders received in the particular day, the number of the total possible sequences is 5! = 120. A total of 120 simulation runs are performed to investigate every possible sequence combination of the five sample orders.

The order sequences and their corresponding total set-up costs are displayed in Figure 7.

From the results shown in Figure 7, we can obtain the minimum total set-up cost is $249.99 and the correspond-

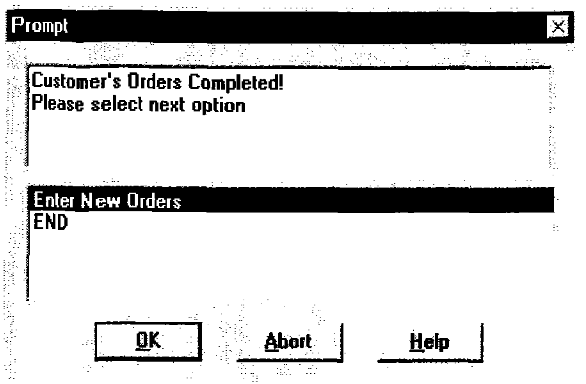

Figure 6: User Selection for "End of Orders"

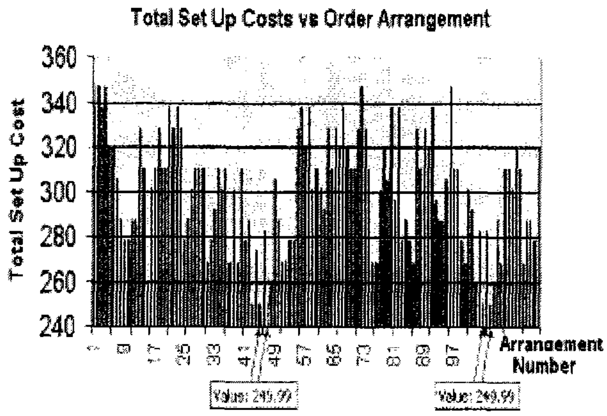

Figure 7: Total Setup Costs for Each Order Sequence

ing order sequences are BECAD, BEDAC, EBCAD and EBDAC.

It is obvious that the simulation method is feasible for solving small size problems. However, it cannot be used to solve large size problems, even those mediate size problems. For example, if the number of orders increases to 10, the number of possible combinations increases to 10!, i.e., a total of 3,628,800 order sequences. It makes the simulation experiment almost impossible to implement. Thus, it attracts us to further investigate how to mathematically model the problem and how to obtain its optimal solution through an efficient and feasible algorithm. This is one of our future research topics.

4 CONCLUDING REMARK

For the case study of a metal casting company in Queensland, Australia, the optimal solutions have been obtained by the simulation. The minimal set-up cost is $249.99 with the optimal order sequences of production, BECAD, BEDAC, EBCAD and EBDAC.

The simulation model is used for accommodating any of the various types and sequences of orders and will generate the corresponding results of set-up costs incurred. However, unless every possible sequence of orders is generated, the model does not automatically enable the user to find the minimum cost. Therefore, the simulation model is most suitable for performing various scenario analyses. The model presents a method for assessing customer' orders and highlights the cost consequences linking to the inefficient time spent in the change of set-up for the machines in the manufacturing department. The model may be expanded to include the concerns of more sustainable issues such as the efficient use of energy and material and the cost and re-melting of scrap metal. This type of simulation and modeling development encompasses the use of a systems approach where the interacting factors of a system under investigation is facilitated to provide a framework for considering all its objectives, methods and possible outcomes (Chestnut 1967).

The user input conditions have considered the initial set-up of all three Alloy Type, Structure Type and Diameter Size. As presented in the previous sections, the results of the minimal set-up costs are based on the initial set-up conditions of Alloy Type 1, Conventional Structure Type and Diameter Size 10. Given any other initial conditions, the output of the simulation may differ in value and best order sequence. Future research work along this direction will focus on mathematically modeling problems of optimizing sequences of production based on a generic setting of customers and developing feasible and efficient algorithms for optimizing the sequences of production.

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